Claims

[c1] A magnetically enhanced plasma processing apparatus comprising:
an anode;
a cathode that is positioned adjacent to the anode and forming a gap there between;
an ionization source that generates a weakly-ionized plasma proximate to the cathode;
a magnet that is positioned to generate a magnetic field proximate to the weakly-ionized plasma, the magnetic field substantially trapping electrons in the weakly-ionized plasma proximate to the cathode;
a power supply that produces an electric field across the gap, the electric field generating excited atoms in the weakly-ionized plasma and generating secondary electrons from the cathode, the secondary electrons ionizing the excited atoms, thereby creating a strongly-ionized plasma comprising a plurality of ions; and
a voltage supply that applies a bias voltage to a substrate that is positioned proximate to the cathode, the bias voltage causing ions in the plurality of ions to impact a surface of the substrate in a manner that causes etching of the surface of the substrate.

[c2] The apparatus of claim 1 wherein the electric field comprises a quasi-static electric field.

[c3] The apparatus of claim 1 wherein the electric field comprises a pulsed electric field.

[c4] The apparatus of claim 1 wherein a rise time of the electric field is chosen to increase an ionization rate of the excited atoms in the weakly-ionized plasma.

[c5] The apparatus of claim 1 wherein a rise time of the electric field is chosen to increase an etch rate of the surface of the substrate.

[c6] The apparatus of claim 1 wherein the weakly-ionized plasma reduces the probability of developing an electrical breakdown condition between the anode and the cathode.

[c7] The apparatus of claim 1 wherein the ions in the plurality of ions impact the surface of the substrate so as to cause substantially uniform etching of the surface of the substrate.

[c8] The apparatus of claim 1 wherein the ions in the plurality of ions impact the surface of the substrate so as to cause anisotropic etching.

[c9] The apparatus of claim 1 wherein a volume between the anode and the cathode is chosen to increase an ionization rate of the excited atoms and molecules in the weakly-ionized plasma.

[c10] The apparatus of claim 1 wherein the ionization source is chosen from the group comprising a UV source, an X-ray source, an electron beam source, an ion beam source, an inductively coupled plasma source, a capacitively coupled plasma source, a microwave plasma source, an electrode, a DC power supply, and an AC power supply.

[c11] The apparatus of claim 1 wherein the power supply generates an electrical pulse that produces the electric field across the gap.

[c12] The apparatus of claim 11 wherein at least one of a pulse amplitude and a pulse width of the electrical pulse is selected to increase a rate of etching of the surface of the substrate.

[c13] The apparatus of claim 1 wherein the bias voltage is selected to control ion energy of the ions in the plurality of ions that impact the surface of the substrate.

[c14] The apparatus of claim 1 wherein the electric field generates ions and excited atoms in the weakly-ionized plasma and generates secondary electrons from the cathode, the secondary electrons ionizing the excited atoms, excited molecules, neutral atoms and neural molecules, thereby creating the strongly-ionized plasma.

[c15] A method of magnetically enhanced plasma processing, the method comprising: ionizing a feed gas to generate a weakly-ionized plasma proximate to a cathode;

generating a magnetic field proximate to the weakly-ionized plasma, the magnetic field substantially trapping electrons in the weakly-ionized plasma proximate to the cathode;

applying an electric field across the weakly-ionized plasma that excites atoms in the weakly-ionized plasma and that generates secondary electrons from the cathode, the secondary electrons ionizing the excited atoms, thereby creating a strongly-ionized plasma comprising a plurality of ions; and

applying a bias voltage to a substrate that is positioned proximate to the cathode, the bias voltage causing ions in the plurality of ions to impact a surface of the substrate in a manner that causes etching of the surface of the substrate.

[c16] The method of claim 15 wherein the applying the electric field comprises applying the electric field at a constant power.

[c17] The method of claim 15 wherein the applying the electric field comprises applying the electric field at a constant voltage.

[c18] The method of claim 15 wherein the applying the electric field comprises applying a quasi-static electric field.

[c19] The method of claim 15 wherein the applying the electric field comprises applying an electrical pulse across the weakly-ionized plasma.

[c20] The method of claim 19 further comprising selecting at least one of a pulse amplitude and a pulse width of the electrical pulse to increase an ionization rate of the strongly-ionized plasma.

[c21] The method of claim 19 further comprising selecting at least one of a pulse amplitude and a pulse width of the electrical pulse to cause the strongly-ionized plasma to be substantially uniform in an area adjacent to the surface of the substrate.

[c22] The method of claim 19 further comprising selecting at least one of a pulse amplitude and a pulse width of the electrical pulse to increase a rate of etching of the surface of the substrate.

[c23] The method of claim 15 wherein ions in the plurality of ions impact the surface of the substrate in a substantially uniform manner.

[c24] The method of claim 15 wherein the strongly-ionized plasma is substantially uniform proximate to a surface of the substrate.

[c25] The method of claim 15 wherein the peak plasma density of the weakly-ionized plasma is less than about 10^{12} cm^{-3}.

[c26] The method of claim 15 wherein the peak plasma density of the strongly-ionized plasma is greater than about 10^{12} cm^{-3}.

[c27] The method of claim 15 further comprising controlling a temperature of the surface of the substrate.

[c28] The method of claim 15 wherein the ionizing the feed gas comprises exposing the feed gas to at least one of an electric field, a UV source, an X-ray source, an electron beam source, an ion beam source, an inductively coupled plasma source, a capacitively coupled plasma source, a microwave source, a DC power supply, and an AC power supply.

[c29] The method of claim 15 wherein the bias voltage is selected to control an ion energy of the ions in the plurality of ions that impact the surface of the substrate.

[c30] A method of magnetically enhanced plasma processing, the method comprising:
ionizing a volume of feed gas to form a weakly-ionized plasma proximate to a cathode;
generating a magnetic field proximate to the weakly-ionized plasma, the magnetic field substantially trapping electrons in the weakly-ionized plasma proximate to the cathode;
applying an electrical pulse across the weakly-ionized plasma to generate a strongly-ionized plasma comprising a first plurality of ions;
exchanging the strongly-ionized plasma with a second volume of feed gas while applying the electrical pulse across the second volume of feed gas to generate a strongly-ionized plasma comprising a second plurality of ions; and

applying a bias voltage to a substrate that is positioned proximate to the cathode, the bias voltage causing ions in the first and the second plurality of ions to impact a surface of the substrate in a manner that causes etching of the surface of the substrate.

[c31] The method of claim 30 wherein the exchanging the strongly-ionized plasma comprises exchanging substantially all of the strongly-ionized plasma with a second volume of feed gas.

[c32] The method of claim 30 further comprising selecting at least one of a pulse amplitude and a pulse width of the electrical pulse that increases an ionization rate of the strongly-ionized plasma.

[c33] The method of claim 30 further comprising selecting at least one of a pulse amplitude and a pulse width of the electrical pulse that causes the strongly-ionized plasma to be substantially uniform in an area adjacent to the surface of the substrate.

[c34] The method of claim 30 further comprising selecting at least one of a pulse amplitude and a pulse width of the electrical pulse to increase a rate of etching of the surface of the substrate.

[c35] The method of claim 30 wherein the applying the electrical pulse across the weakly-ionized plasma excites atoms in the weakly-ionized plasma and generates secondary electrons from the cathode, the secondary electrons ionizing the excited atoms, thereby creating the strongly-ionized plasma.

[c36] A magnetically enhanced plasma processing apparatus comprising:
means for ionizing a feed gas to generate a weakly-ionized plasma proximate to a cathode;
means for generating a magnetic field proximate to the weakly-ionized plasma, the magnetic field substantially trapping electrons in the weakly-ionized plasma proximate to the cathode;
means for applying an electric field across the weakly-ionized plasma that excites atoms in the weakly-ionized plasma and that generates secondary electrons from the cathode, the secondary electrons ionizing the excited atoms,

thereby creating a strongly-ionized plasma comprising a plurality of ions; and means for applying a bias voltage to a substrate that is positioned proximate to the cathode, the bias voltage causing ions in the plurality of ions to impact a surface of the substrate in a manner that causes etching of the surface of the substrate.

[c37] A magnetically enhanced plasma processing apparatus comprising:
means for ionizing a volume of feed gas to form a weakly-ionized plasma proximate to a cathode;
means for generating a magnetic field proximate to the weakly-ionized plasma, the magnetic field substantially trapping electrons in the weakly-ionized plasma proximate to the cathode;
means for applying an electrical pulse across the weakly-ionized plasma to generate a strongly-ionized plasma comprising a first plurality of ions;
means for exchanging the strongly-ionized plasma with a second volume of feed gas while applying the electrical pulse across the second volume of feed gas to generate a strongly-ionized plasma comprising a second plurality of ions; and
means for applying a bias voltage to a substrate that is positioned proximate to the cathode, the bias voltage causing ions in the first and the second plurality of ions to impact a surface of the substrate in a manner that causes etching of the surface of the substrate.